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Object Perception by Visually Impaired People at Different Light Levels

FRANS W. CORNELISSEN,*† ANNETJE BOOTSMA,* AART C. KOOIJMAN*†

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We investigated the relationship between the illumination level and the ability of visually impaired subjects to detect and recognize objects in a realistic visual environment. Subjects often continued to show substantial improvement at light levels where normal subjects have reached maximum performance. Integrated contrast sensitivity, a summary measure for the contrast sensitivity function, was better at predicting performance than either visual acuity or peak contrast sensitivity. However, when combined, the latter two predicted performance as well as the former. We conclude that when we try to find the best illumination for orientation and day-to-day activities we should optimize it for both visual acuity and contrast sensitivity.

Visual impairment Contrast sensitivity Visual acuity Object detection Object recognition Illumination

INTRODUCTION

Clinically oriented investigations of the relationship between illumination and visual performance have mainly been concerned with vision of detail and reading (e.g. LaGrow, 1986; Hartmann, Scheffzyk-Hagl & Lachenmayr, 1980; Cornelissen, Kooijman, Dumbar, van der Wildt & Nijland, 1991). Less is known about light levels required by visually impaired subjects to detect and recognize relatively large objects, something that is important in many daily tasks and orientation and mobility.

For visually healthy subjects, performance at tasks that require seeing detail depends upon the level of illumination. Although this depends to some extent upon the exact task, we can generally say that up to about 10 lx the rate of improvement in resolution with increasing illuminance is fairly large. Increasing light levels above 10 lx helps little to improve performance (Weston, 1953; Boyce, 1973; Smith & Rea, 1979; Cornelissen *et al.*, 1991). In The Netherlands, recommended lighting for tasks in which vision of detail is important (such as office tasks) is in the order of 200–800 lx. Light levels needed for orientation and mobility are considered to be lower [10–200 lx (van Bergem-Jansen & Padmos, 1989)].

For persons with impaired vision, optimal performance for seeing detail and reading can be critically dependent on light levels that may either be higher or lower than normal levels. Furthermore, the range over which optimal performance is found can be reduced (Hartmann *et al.*, 1980; Cornelissen *et al.*, 1991; Cornelissen, Kooijman, Bootsma, van Schoot & van der Wildt, 1994). Similarly, we may expect that light levels needed for perceiving larger objects will often differ from normal. One reason for carrying out this study was to evaluate the latter hypothesis. The second reason was to investigate what clinical measure(s) of visual performance (visual acuity or contrast sensitivity) could best predict real life perceptual abilities.

MATERIALS AND METHODS

Test room, objects and light levels

As we wanted to test object perception in a situation that was realistic, we used a "calibrated" visual environment with real objects to measure detection and recognition capacities of our low vision subjects. The experiments were conducted in the "Light Lab" at Visio's Northern Regional Institute in Haren, The Netherlands. Here, an extensive control of the visual environment is possible and it can be used to "simulate" a living room, work place or other environment. In the current experiment we used a set up that approximately resembled a living room (Fig. 1). It measures 6.10 × 4.40 m and is 2.83 m high. Illumination is provided by fluorescent tubes (Philips TLD50W/84 HF, TLD50W/83 HF, TLD50W/94 HF, Eindhoven, The Netherlands) that are mounted in ETAP low luminance armatures (U6-ISOLUM®, ETAP, Breda, The Netherlands). The

*Laboratory for Experimental Ophthalmology (LEO), Center for Behavioural Cognitive and Neurosciences (BCN), University of Groningen, P.O. Box 30001, 9700 RB Groningen, The Netherlands.
†Visio, National Foundation for the Visually Impaired and Blind, Regionale Instelling Noord, Haren, The Netherlands.

illumination can be varied between 0 and 5000 lx. Illuminance was measured in the horizontal plane at a height of 0.74 m with a lux-meter (Metrawatt $M \times 4$).

To calibrate the perceptibility of the objects in our "real world" visual environment, we first established how normal subjects' ability to perceive objects was related to the ambient light level. Based on these results we selected 25 objects of various sizes and contrasts. To determine the illumination level required for the detection of these objects, normal subjects ($n = 12$) wore a pair of goggles with neutral density filter ($N = 3.58$) to reduce the effective illuminance range to 0.001–1 lx (all of our test objects could be perceived by the normal subjects at levels of 1 lx or more). Performance was measured at six levels of illumination (0.005, 0.015, 0.05, 0.15, 0.5 and 1.0 lx). Criteria for selecting a test object were that it had to be recognized by all subjects and that the light level at which it was detected or recognized was similar for all subjects (our criterion was that 11 out of 12 subjects must have detected it within three illumination steps). Furthermore, we selected the objects in such a way that they became detectable over an extensive range of illuminations. Most objects were fairly large (like tables, chairs or coffee mugs) as our emphasis was on objects people need to see when carrying out daily living tasks or moving around a room. One of the "objects" was the face of the experimenter. Appendix A lists the objects, their contrast [defined as $(L_{\text{backgroud}} - L_{\text{object}})/(L_{\text{background}} + L_{\text{object}})$ with L being luminance], their approximate angular size at the position of the observer, and the recognition criteria that were applied. In the actual experiment, the visually impaired subjects were tested at eight light levels (1.6, 5, 16, 50, 160, 500 1600 and 5000 lx).

Contrast sensitivity and visual acuity

Binocular contrast sensitivity (CS) was measured with the use of a Vistech VCTS 6500 Contrast Sensitivity Chart (Vistech Consultants Inc., Dayton, Ohio). Although the reliability of the Vistech chart has been questioned (Reeves, Wood & Hill, 1991; Rubin, 1988; Kennedy & Dunlap, 1990), it was the only commercially available printed test for measuring a contrast sensitivity function with sinusoidally modulated targets of different spatial frequencies, when we performed the experiment. We needed a printed test, as we wanted to measure CS also at very high illuminances. CS was measured at four levels of illumination (5, 50, 500 and 2500 lx, measured in the plane of the chart). We used Vistech targets A (0.5 c/deg), B (1 c/deg), C (2 c/deg) and D (4 c/deg) at 1 m and C (6 c/deg), D (12 c/deg), and E (18 c/deg) at 3 m (see e.g. van den Brom, Kooijman & Blanksma, 1992). Targets were 2.3 deg (at 3 m) disks containing the modulation. CS was taken to be the value that corresponded with the last object identified correctly. Peak CS was the highest sensitivity measured (irrespective of the spatial frequency of the target). Integrated contrast sensitivity (ICS) (van Meeteren & Vos, 1972) is the surface under the CS curve when plotted on linear scales (see Fig. 3).

Binocular visual acuity (VA) was measured using the TNO Landolt-C chart (TNO Soesterberg, The Netherlands) at the same four levels of illumination (5, 50, 500 and 2500 lx) presented at 3 m. VA was taken to be the

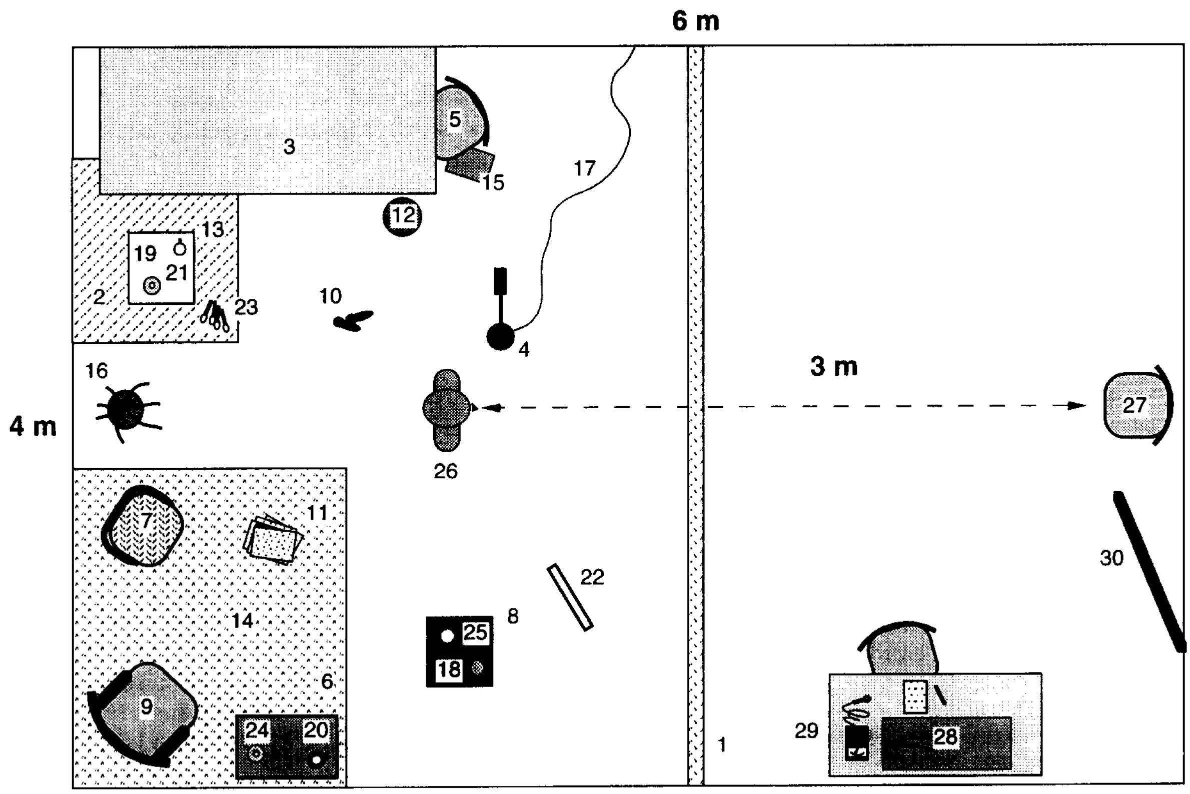

FIGURE 1. The objects in the "Light-Lab". Numbers refer to Appendix A.

value that corresponded with the last line of which all targets were identified correctly.

The light levels tested at in the object perception experiment have different values as those used to measure CS and VA as the former were measured in the horizontal plane, whereas the latter where measured in the vertical plane of the chart. A level of 50 lx in the vertical plane corresponded with 100 lx in the horizontal plane.

Procedure

The procedure was explained to the subject who was then guided into the dark laboratory. The subject sat on a chair at one end of the room and the test objects were located on the opposite side. After 10 min of dark adaptation, illumination was introduced at the lowest level at which the subject was to be tested. Subjects had both eyes open. The subject was asked to name all objects in the room that could be detected or recognized. The level at which each test object could be detected or recognized was recorded. Ample time was given for looking around the room and naming all objects that had been seen. The illumination was then adjusted to the next level. This continued until the highest level had been reached or all objects had been recognized. After a new period of dark adaptation CS and VA were measured using the same sequence of illumination levels.

Subjects

Visually impaired subjects were volunteers recruited from amongst the clients of Visio's Northern Regional Institute in Haren, The Netherlands. The 23 subjects were of various ages and had various ophthalmological ocular disorders. They had given their informed consent. Appendix B lists their main visual pathology, sex, age, and binocular corrected distance VA. Visually impaired subjects wore their habitual optical correction while performing the experiment. All 12 subjects that had participated in the pilot experiment had normal vision when wearing their habitual optical correction and they had no known visual anomalies.

RESULTS

For the analysis, we needed a measure that allowed us to characterize how well visually impaired subjects perceived objects in the environment. Therefore, we determined for each subject the cumulative number of objects that could be detected and recognized at eight different light levels (shown in Fig. 2). It is immediately clear that most visually impaired subjects benefit from increasing the illumination level. For many subjects, the illumination changes have dramatic effects upon their visual abilities. It is noteworthy that the light levels at which improvements occur are often well above the level that normal subjects needed to recognize all objects (1 lx).

Many subjects (e.g. 1, 2 and 9) needed high light levels to even detect the more obvious objects. Another important observation is that three subjects could not tolerate the higher light levels (2, 3 and 9). For these subjects, data points at these light levels are missing.

We used the object perception data to evaluate how well CS and VA can predict visual performance in a realistic situation. Specification of CS raises some problems in that it is a two-dimensional measure. Our realistic visual environment, like any real world scene, contained test objects of different sizes and contrast. Objects contain a range of spatial frequencies which vary according to their size and the viewing distance. For this reason, it is quite conceivable that performance over a broad band of spatial frequencies is relevant to the diverse individual tasks that were used in our experiment. It has been suggested that ICS can be used to summarize the information in the CS function as it represents the total amount of visual information that is assimilated by the visual system and that, therefore, is available to the observer (van Meeteren & Vos, 1972; van Meeteren, 1973). ICS is represented by the area under the CS function (illustrated in Fig. 3). Another possibility is to use subjects' peak CS (indicated by the arrow in Fig. 3), which expresses the maximum sensitivity of the visual system (Marron & Bailey, 1982; Rubin & Legge, 1989).

For each subject, and for each of the four light levels at which we had measured CS and VA (5, 50, 500 and 2500 lx), we determined the cumulative numbers of objects that had been detected and recognized (if necessary the latter were determined by linear interpolation). As an example, Fig. 4 shows scatter plots of log VA, log peak CS and log ICS vs number of objects recognized. Information about the illuminance level at which the measures had been obtained is eliminated. At first glance, all graphs show an approximately linear increase in the number of objects recognized with increasing values along the x-axis. The plots for peak CS and VA appear to show more spread than the one for ICS.

To statistically compare the predictive power of the measures, we performed a multiple regression analysis using log VA, log peak CS and log ICS as independent, and object detection and recognition performance as dependent variables. The results are shown in Table 1. ICS explains significantly more of the variance in the performance data than either peak CS or VA ($P < 0.001$). It explains about 70% of the variance in the detection task, and nearly 80% of that in the recognition task. Peak CS is a slightly better predictor than VA, but the difference is not significant. Adding VA as an independent variable to ICS did not improve the predictions whereas adding VA to peak CS did. Interestingly, the latter combination of variables can explain as much of the variance as ICS.

DISCUSSION

The aim of this study was to investigate the influence of illumination on object perception, as understanding this relationship may lead to improvements in the visual rehabilitation of partially sighted subjects. In general, we found that object detection and recognition improved when we increased light levels. This is not so surprising in

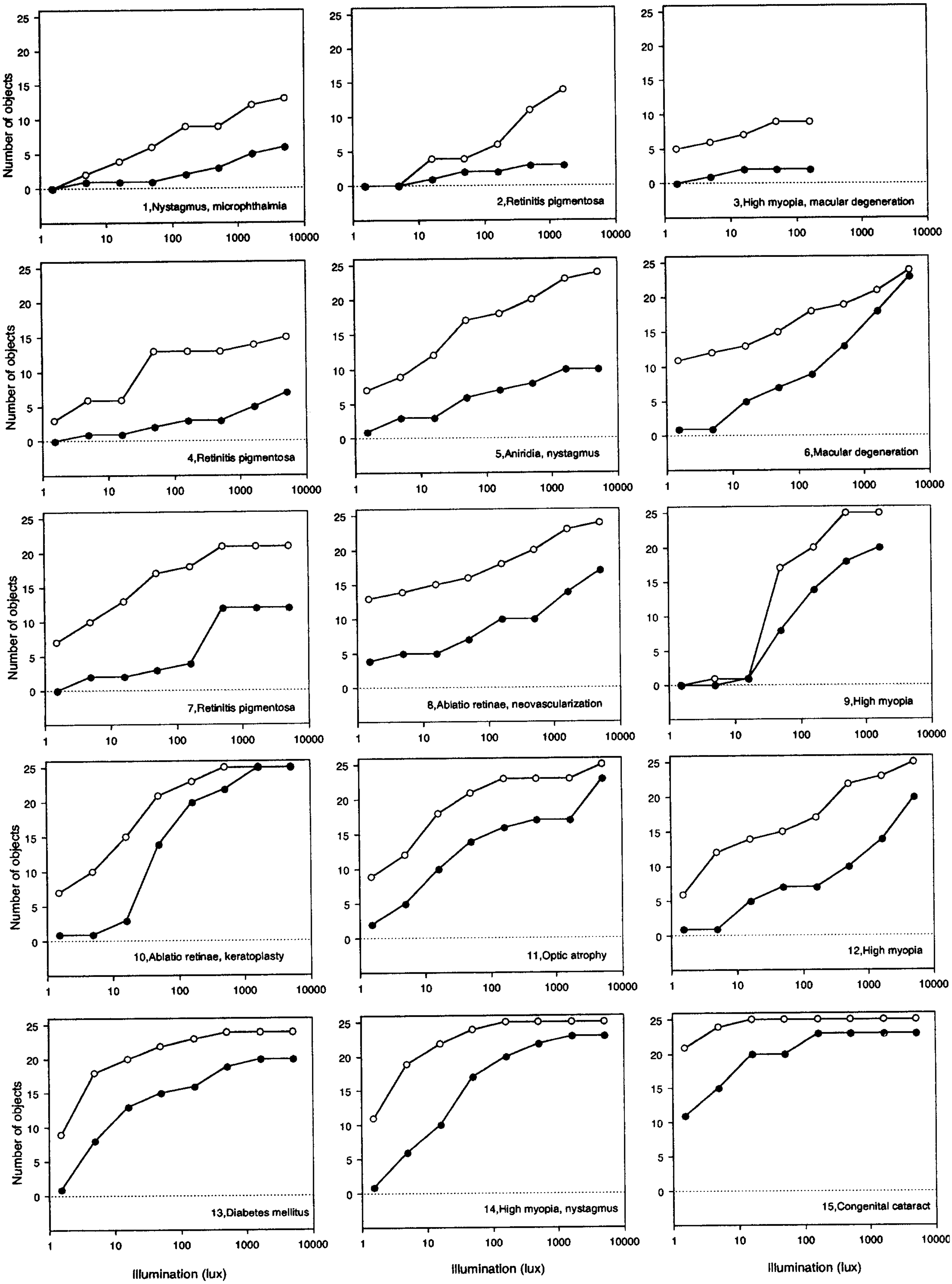

FIGURE 2. *Caption on facing page.*

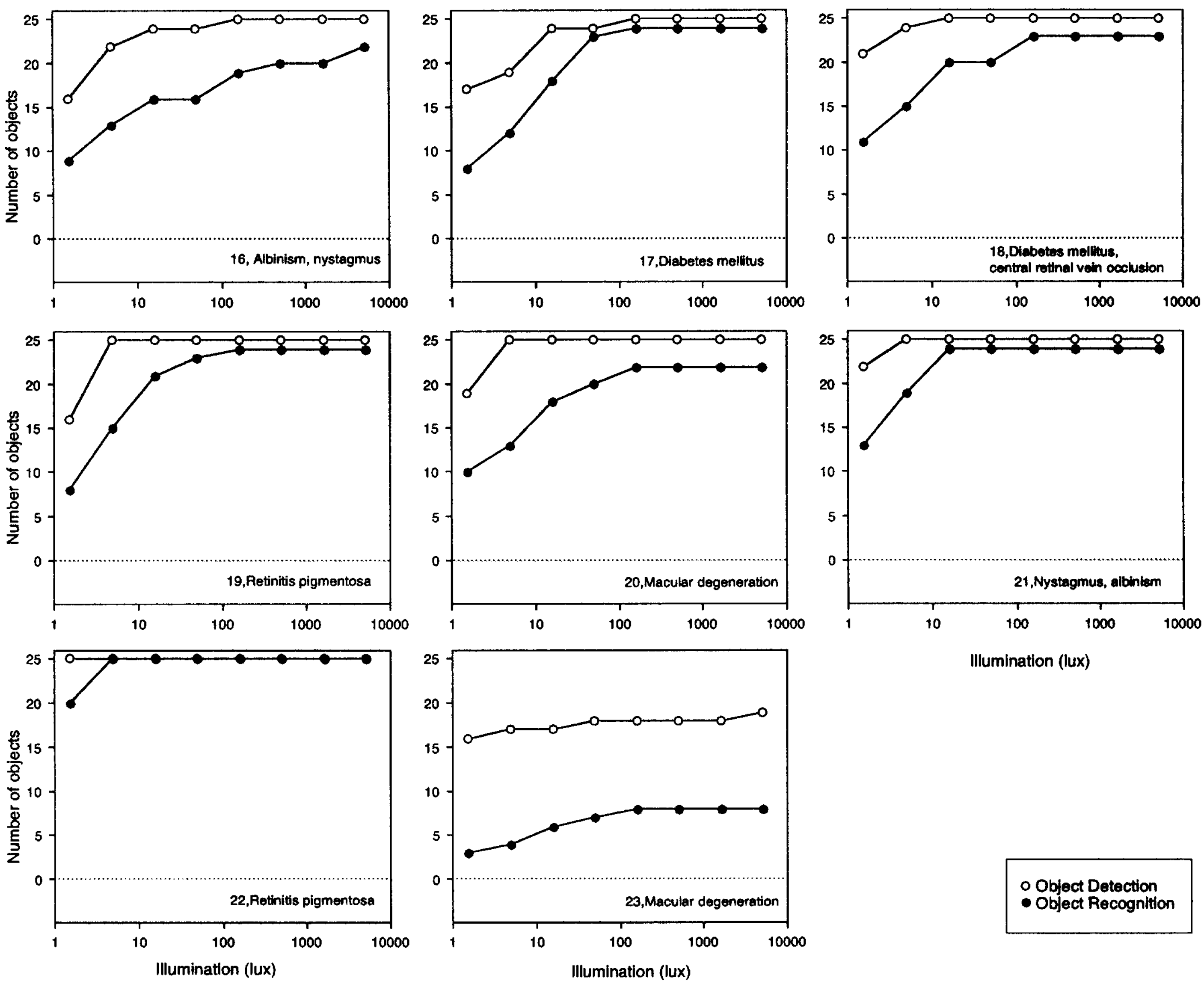

FIGURE 2. Cumulative number of objects detected (○) and recognized (●) at different levels of illumination. Data for 23 visually impaired subjects (numbers refer to Appendix B). It is important to realize that even at the lowest light level (1.6 lx) normal sighted subjects could recognize all the objects. Some curves saturate because the objects were limited in size and contrast.

itself; performance of normal sighted people is also dependent upon the light level (Weston, 1953; Boyce, 1973; Smith & Rea, 1979; Cornelissen *et al.*, 1991). However, for the majority of our subjects, object detection and recognition continued to improve well into moderate to high illumination levels. This occurred despite the fact that the objects in general were fairly large and could all be recognized by normal subjects at low light levels (< 1 lx). In general, for most subjects, performance improved with increased light level. However, some of them showed performance decrease at higher levels of illumination. Two subjects (2 and 9, Appendix B) reported that the highest light level (5000 lx) was too uncomfortable to continue the experiment. A third one (3) even found light levels over 500 lx to be too bright. That vision can be better with less light has been found in other studies as well (Hartmann *et al.*, 1980; Cornelissen *et al.*, 1991, 1994). We conclude that for many of our visually impaired subjects individually adapted illumination is important. Unfortunately, it will be difficult to provide standardized optimal levels. Even subjects with a similar pathology may have rather different lighting needs. Furthermore, the required level is task (Cornelissen *et al.*, 1994) and age (Boyce, 1973; Taub & Sturr, 1991) dependent. Subjective comfort criteria may further enlarge individual differences. Our experiment serves to stress the importance of determining lighting needs for every patient indiviually.

We examined how well subjects' VA and CS could predict their object detection and recognition performance. We analysed CS in terms of peak CS and ICS. As our measure of performance we took the cumulative number of objects that had been detected or recognized. ICS was found to be a better predictor of visual performance than either VA or peak CS alone. This may have partly been due to the fact that integrating, like

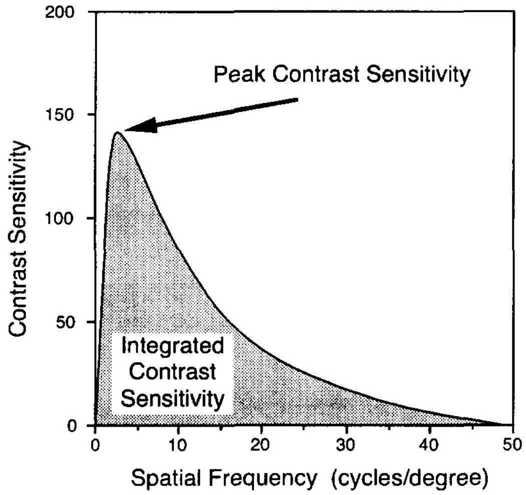

FIGURE 3. ICS represents the total amount of visual information that is assimilated by the visual system and is depicted by the area under the contrast sensitivity curve (note that it is calculated on a linear x and y base). The ICS data we obtained for normal subjects were comparable to foveal data measured with a 2.8 × 2.8 deg field (comparable to a Vistech target at 3.0 m) by van Meeteren and Vos (1972). Peak contrast sensitivity is the highest sensitivity that was measured, irrespective of spatial frequency (indicated by the arrow).

averaging, reduced the spread in the data. However, this influence could not explain the difference (see footnotes to Table 1).

A very interesting finding was that peak CS combined with VA predicted task performance as well as ICS. Apparently, to best predict performance on visually complex tasks, sensitivity to both low and high spatial frequencies provides relevant information. This result complements the finding that CS functions of low vision (Pelli, Rubin & Legge, 1986) and elderly (Rohaly & Owsley, 1992) subjects could be fitted by the same parabolic function by shifting it along the spatial frequency and CS axes. The position of the CS curve could be estimated on the basis of a measurement of high contrast VA and a single measurement of CS with letters of various contrast. Our current work extends these findings by showing that the combination of peak CS and VA can quite accurately predict visual functioning in a real life situation.

The relationship between clinical measures and performance on everyday visual tasks had been addressed previously. For normally sighted subjects, Owsley and Sloane (1987) investigated the predictive power of CS and VA for performance on a task that required detecting and recognizing road signs, faces, and common objects that were depicted on slides. CS at low and middle spatial frequencies and age were found to be the best predictors for task performance (we found that the predictive value of low CS and peak CS were very similar; see footnotes to Table 1). VA was found to be a redundant parameter as it was strongly correlated with age. In our study, the population consisted of visually impaired subjects and VA did have some additional predictive value. In visually impaired subjects, a strong correlation between age and VA is not expected.

An important methodological difference with our experiment was that Owsley and Sloane varied the contrast at which their slides, and thus the objects, were presented, something that does not commonly happen in the real world. In our experiment, the physical contrast of the objects remained constant while subjects' CS was modulated (by varying the illumination), something more likely to occur. Peak CS had also been found to be a good predictor for orientation and mobility performance (Marron & Bailey, 1982) and reading (Rubin & Legge, 1989) in low vision patients. The conclusions of these studies and our own are similar in that they assign great predictive value for real task performance to CS and much less value to VA. We infer from our results that when we want to use illumination to improve visual performance both CS and VA should be evaluated and optimized.

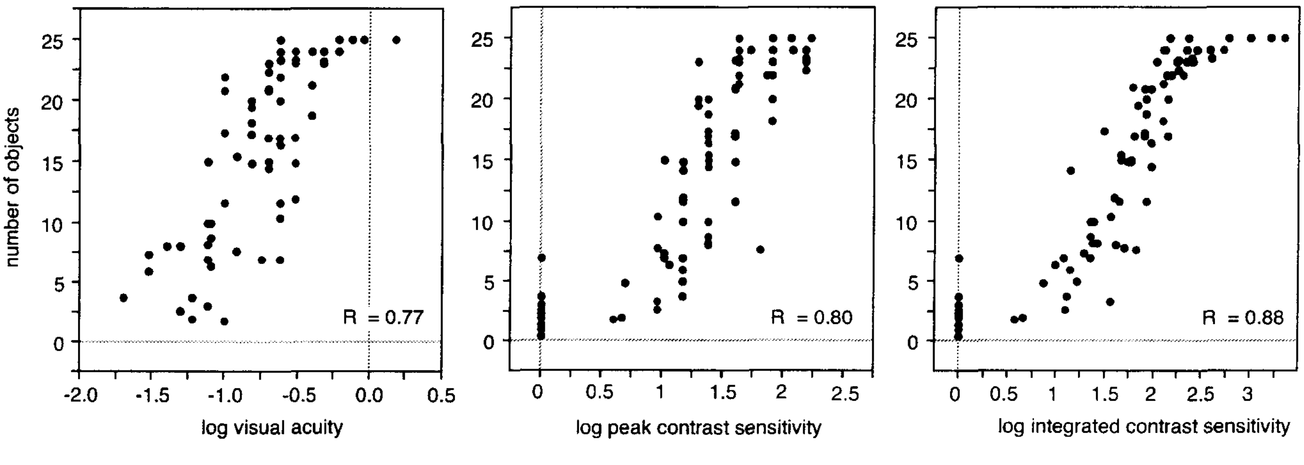

FIGURE 4. Number of objects that visually impaired subjects recognized as a function of log VA, log peak CS and log ICS. Number of data points in the graphs may be less than 92 (23 subjects × 4 light levels) due to superposition and to the fact that we could not obtain data at very high illuminances for all subjects. As the Vistech chart cannot be used to measure sensitivities below 0.5 there is a clustering of datapoints at 0 in the plots for peak CS and ICS. Correlations for all variables were highly significant ($P < 0.001$).

TABLE 1. R^2 for regression models

	Dependent variable	
Independent variable(s)	Object detection	Object recognition
Integrated contrast sensitivity*†	0.69	0.78
Peak contrast sensitivity‡	0.63	0.64
Visual acuity	0.43	0.59
Integrated contrast sensitivity and visual acuity§	0.69	0.80
Peak contrast sensitivity and visual acuity¶	0.68	0.77

*Integrated contrast sensitivity explains significantly more of the variance in the object detection and recognition data than either VA or peak CS, ($P<0.01$, z-transformation).

†The "superiority" of ICS may have partly been due to the fact that integrating, like averaging, reduced the spread in the data. This influence, however, is not large enough to explain all of the difference. When, for example, we calculated peak CS by averaging sensitivities measured for three targets (the one at which the actual peak CS was found, the next one lower and the next one higher in spatial frequency) explained variance increased only slightly (detection $R^2=0.67$, recognition $R^2=0.70$).

‡Using average CS at 0.5 and 1.0 c/deg (approximately the spatial-frequency band observers use for recognizing letters on the Pelli–Robson CS chart when used at a viewing distance of 1 m (Pelli, Robson & Wilkins, 1988; Regan, Raymond, Ginsburg & Murray, 1981; Solomon & Pelli 1994) gave similar results as for peak CS in this analysis (detection $R^2=0.68$, recognition $R^2=0.62$; when combined with VA, detection $R^2=0.73$, recognition $R^2=0.78$).

¶Adding VA to peak CS significantly improved the model ($P<0.01$). The two lower models explain the variance in the object detection and recognition data equally well.

§Adding VA as an independent variable to ICS did not significantly improve the model.

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APPENDIX A

Objects in the "Light-Lab"

No.	Object	Contrast	Size	Recognition criteria	Contrast	Size
1	Border	57	1.6	Border	57	1.6
2	Vinyl carpet	23	12.0	Type/form	23	11.0
3	Table	80	6.3	Size of table (large)	60	0.4
4	Black lamp	67	4.5	Name lampshade	27	1.3
5	Desk chair	62	0.4	Type of chair	33	2.5
6	Drawer	62	9.6	See opened drawer	71	1.2
7	White chair	33	5.0	Name seat and armrest	20	1.5
8	Black table	82	11.0	Type and form of table	33	0.3
9	Armchair	33	6.2	Large wooden chair	33	1.6
10	Shoes	38	4.6	Women's shoe	76	0.6
11	Newspaper	50	3.5	Newspaper or magazine	50	2.8
12	Trash can	44	8.1	Form of can (round)	29	3.6
13	White table	43	8.0	Type and form of table	11	0.2
14	Carpet	33	15.0	Carpet with patterns	33	1.9
15	Box	43	3.5	Position of opening	82	2.5
16	Plant*					
17	Cable	88	0.2	Position and direction	88	0.2
18	Black mug	33	1.4	Position of ear	48	0.6
19	Milk bottle	6	1.3	Type of bottle	54	0.3
20	Mug on black	33	1.1	Position of ear	33	0.4
21	Mug on white	5	1.0	Position of ear	5	0.3
22	Ruler	29	0.7	Ruler or white border	29	0.7
23	Spoons	20	2.4	Number of spoons (4)	20	0.1
24	Rum bottle	11	1.2	Type of bottle or see label	11	0.3
25	Ashtray	50	1.7	Ashtray	50	1.7
26	Face	20	3.0	Opened mouth, expression	20	0.5

*Plant died in the course of the experiments and was excluded from the analysis.

Not used for detection or recognition

26	Position of test charts at 3 m
27	Position of subect during experiment
28	Lighting control panel
29	Lux meter
30	Entrance to the "light-lab"

See Fig. 1 for lay-out of objects. Background for calculating contrast was the immediate vicinity of the object. Size is size of the largest detail of the object in degrees. Recognition criteria lists that part of the object that had to be named or characterized in order for the object to be scored as "recognized". Second row of contrast and size values are the part that was relevant for recognition. These values are provided to give an impression of the variety in contrast and sizes of the objects in the "Light-Lab".

APPENDIX B

No.	Visual pathology	Sex*	Age	VA†
1	Nystagmus, microphthalmia	F	27	0.02
2	Retinitis pigmentosa	M	46	0.4
3	High myopia, macular degeneration	F	56	0.06
4	Retinitis pigmentosa	F	56	0.06
5	Aniridia, nystagmus	F	19	0.08
6	Macular degeneration	F	54	0.2
7	Retinitis pigmentosa	M	42	0.3
8	Ablatio retinae, neovascularization	M	76	0.1
9	High myopia	F	27	0.4
10	Ablatio retinae, keratoplasty	M	41	0.48
11	Optic atrophy	F	21	0.3
12	High myopia	F	65	0.24
13	Diabetes mellitus	F	61	0.15
14	High myopia, nystagmus	F	42	0.2
15	Congenital cataract	M	44	0.2
16	Albinism, nystagmus	F	30	0.24
17	Diabetes mellitus	F	31	0.08
18	Diabetes mellitus, central retinal vein occlusion	M	31	0.48
19	Retinitis pigmentosa	M	13	0.48
20	Macular degeneration	F	53	0.1
21	Macular degeneration	F	50	0.04
22	Nystagmus, albinism	M	34	0.3
23	Retinitis pigmentosa	F	50	1.5

*M, male; F, female.

†Binocular corrected distance visual acuity as measured at 500 lx.